Cortical integration of simple somatosensory and visual input

E.A. Disbrow[1,2], L.A. Krubitzer[3], and T.P.L. Roberts[1]

[1]Biomagnetic Imaging Lab, University of California, San Francisco, USA,
[2]Dept. of Neurology & [3]Dept. of Psychology, University of California Davis USA

1 Introduction

Primates, probably more than most other mammals, have developed a host of complex behaviors that require integration across sensory systems and between sensory systems and the motor system. One such ability is goal- directed reaching. This ability requires the brain to generate body centered coordinates for conjugal eye and hand movements. Thus, there should be regions of the brain, particularly the neocortex, that have access to both visual and somatic inputs, as well as information regarding eye position. One likely site of this multimodal integration is posterior parietal cortex (areas 5 and 7a). Studies in non-human primates indicate that neurons here have somatic receptive fields, and respond to wrist and arm movements, and reaching and grasping [1-3]. Further, neurons in this region participate in integration of visual inputs regarding target location and kinesthetic information regarding the position of the limbs in space [5]; instructed movements [6]; and attention [7, 8]

In humans, activation in posterior parietal cortex to somatosensory stimuli has been described using MEG [9] and limited data indicate that like anterior parietal fields, it is somatotopically organized [10]. In addition, several neuroimaging studies have demonstrated increases in activity in posterior parietal cortex during visually guided and exploratory reaching tasks [11, 12] complex sequential finger movements [13, 14], and with shifts in attention [i.e. 7] The present study represents our first in a series of studies that will examine the complex functions of posterior parietal cortex. Here we use fMRI and MEG to examine the integration of simple somatosensory and visual stimuli.

2 Methods

2.1 Subjects

Magnetoencephalography (MEG) and functional magnetic resonance imaging (fMRI) were used to measure responses in parietal and occipital cortex of 9 and 11 subjects respectively. All studies were performed with the approval of the institutional human studies committee.

2.2 Stimuli

Stimuli were identical for MEG and fMRI experiments. Pneumatically driven mechanical taps (25 pounds per square inch, 30 ms duration) were applied to the distal fingertips of subjects' right digits 2 and 3 with a balloon diaphragm of 1 cm diameter (BTi, San Diego, CA). The visual stimulus was a reversing checkerboard (5.5°x5.75°) presented centrally with fiberoptic goggles (Avotec SilentVision, Jensen Beach, Florida). The three experimental conditions consisted of stimuli presented individually and simultaneously. Patients were given no instructions about attention to the stimuli.

2.3 MEG

Neuromagnetic fields were recorded in a shielded room using a 37-channel biomagnetometer system (Magnes™, BTi, San Diego, CA). The 37 first-order gradiometers are arranged in a concentric radial distribution over a concave surface with an intercoil separation of 2.2 cm and an angular field of view of approximately 70 degrees. The diameter of the sensor array head is 14 cm. Two hundred and fifty epochs of 500ms duration (plus 100ms pre-stimulus) were acquired with a 1.0Hz high-pass cutoff. A sampling rate of 1 kHz was used. The sensor array was positioned over anterior parietal somatosensory cortex. Interstimulus interval was pseudo randomly varied from 3.5 to 4.5 seconds. Epoch data that were time locked to stimulus onset were averaged and bandpass filtered (8-40Hz) before additional analysis.

An anatomic reference frame was established using a digital sensor position indicator. Receivers were used to triangulate the signal from the indicator placed at fiducial reference points on the subject’s head surface, such as the nasion, left and right pre-auricular points. These points were used to define the MEG reference frame in which the source localization was described. Radiological identification of these fiducials on high resolution MRI will allow for the transformation of MEG space into the anatomic (MRI) coordinate system and the anatomical registration of the MEG sources. The computed dipoles were co-registered to individual subjects' MR images (3D SPGR sequence, TR/TE/Flip angle = 35ms/6ms/30°, 1mm spatial resolution) to determine their location in an anatomic context.

2.4 fMRI

Imaging was performed using a standard clinical GE 1.5 Tesla scanner and a whole head coil (GE Medical Systems, Milwaukee, WI). First, an anatomical high-resolution 3D-SPGR (3 dimensional steady precession gradient-recalled) series (acquisition: axial, interleaved, 256x256 matrix, FOV 40x40; 124 slices, 1mm slice thickness, repetition time = 35ms, echo time = 6ms, flip angle = 30°, 1 NEX) was collected for determination of Talairach coordinates and MEG overlay. Then an ultrafast echo planar gradient echo imaging sequence designed to detect variations in local T_2* (repetition time = 2s, echo time = 69ms, flip angle = 60°) was used. A 256 x128 matrix was used with a field of view of 40 x 40 cm, a slice thickness of 5mm (0.5 mm gap) and thus a voxel (three dimensional pixel) size of 1.5 x 1.5 x 5mm.

A single fMRI scan (one stimulus condition) lasted 2 minutes, 20 seconds, during which a total of 70 repetitions of the brain image (5-7 slices) were collected. Each imaging sequence consisted of alternating 20 second intervals of stimulation and rest.

During scanning, each subject's head was held in position with a plastic pillow (Olympic Vac-Pac, Olympic Medical, Seattle WA) filled with Styrofoam packing beads. The air was removed from the pillow so that it became rigid and conformed to the contours of the head.

2.5 Data analysis

For MEG, the parameters that were evaluated as a function of uni- or bimanual stimulation include the amplitude of the evoked response, root mean square activity across channels (RMS). The position, orientation, and strength of the estimated dipoles were computed using a single equivalent current dipole model.

For fMRI, data analysis and display were done using the software package Stimulate. Cross-correlation analysis was used to determine significantly active voxels. A correlation threshold of r=0.3 was used with a cluster threshold of four voxels. Patterns of activation were superimposed on to high resolution 3D images. Voxel number comparisons between conditions were made using paired t-tests for both MEG and fMRI data.

3 Results

Somatosensory stimulation resulted in a single current source dipole in anterior parietal cortex (SI; latency=40ms) on MEG, and significant fMRI-measured activation in SI, and SII. Visual stimulation resulted in a current source in posterior occipital cortex on MEG and two large areas of fMRI measured activation, one in primary visual cortex and one in the cuneus.

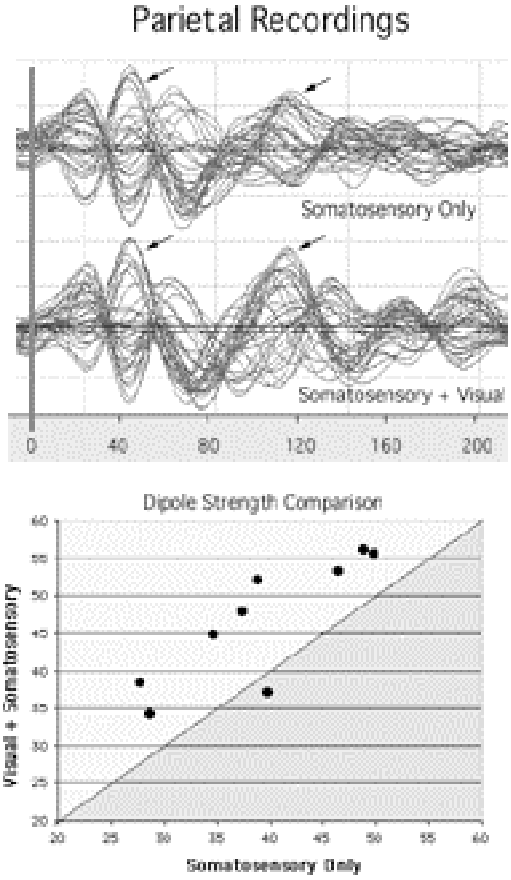

Figure 1: *The upper panel contains MEG recordings during somatosensory (top) and simultaneous somatosensory and visual stimulation. Note thatpeak at 100 ms is larger for multimodal stimulation. The bottom panel is a plot of dipole strength (RMS) for the 100ms peak for somatosensory and multimodal stimulation for all 9 subjects.*

Combined stimulation resulted, on MEG, in an SI dipole and an additional current source in PP (latency=100ms; Figure 1). An additional current source was also seen in the Sylvian fissure in some subjects. FMRI data revealed an increase in posterior parietal activation (often bilateral), while activation in SI was significantly reduced by combined stimulation. Activation in SII did not change. FMRI-measured activation in visual cortex was also significantly reduced, especially in the cuneus.

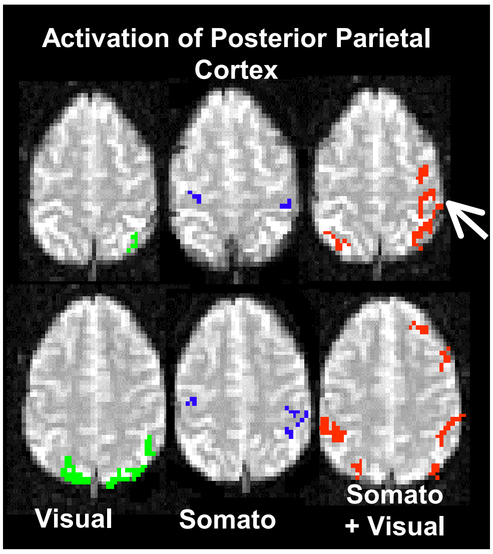

Figure 2: *Two axial fMRI images (top row = superior) for the 3 stimulus conditions (columns). Note the activation in PP for the multimodal condition (arrow). Also, a comparison of occipital cortex illustrates the reduction in activation for the multimodal condition. Voxel count was significantly reduced in visual cortex for both stimuli presented together (mean ± SD, visual=307 ± 164 vs. somatosensory+visual=169 ± 147 voxels, $p<0.01$). Conversely, magnetic field strength was significantly greater for both stimuli combined (visual = 1.76 ± 0.39fT vs. somatosensory + visual = 2.04 ± 0.44fT, $p<0.01$, paired t-test).*

4 Discussion

The results of this study are two fold. First, we demonstrated increased activation in posterior parietal cortex in response to multimodal stimulation in both fMRI and MEG experiments. This result is consistent with data from human and non-human primates suggesting that neurons in this region are involved in the integration of somatosenosry and visual inputs.

The increase in magnetic field strength and voxel count suggest three possible underlying neural mechanisms. It may reflect an increase in the number of neurons responding, an increase in the synchrony of firing, or an increase in the rate of firing.

Our second finding was a discrepancy between results obtained using MEG and fMRI for activation in primary visual and somatsensory cortex. FMRI showed a significant decrease in voxel count in both of these regions under multimodal stimulus conditions, while the MEG data indicated an increase in magnetic field strength emanating from primary sensory cortex for the multimodal condition. The fMRI-measured decrease in primary visual cortex has been noted previously [15, 16], and has been ascribed to shifts in attention. However, we did not manipulate attention in this study; in fact, the stimulus paradigm was completely passive, leaving the effects of attention uncontroled (random). Because the increase in MEG activation is consistent with data from non-human primates, it is possible that the decrease in fMRI voxel count may be due to some methodological artifact, such as capacity limitation of the hemodynamic response. MEG is a direct measure of neural activity while fMRI relies on the indirect blood oxygenation level dependent signal and is therefore subject to additional potential confounds.

References

1. H. Sakata, Y. Takaoka, and A. Kawarasaki, *Brain Research* **64**, 85-102, 1973.
2. W.A. MacKay, M.C. Kwan, J.T. Murphy, and Y.C. Wong, *Neurosci Let* **10**, 235-239, 1978.
3. Y. Iwamura, M. Tanaka, O. Hikosaka, and M. Sakamoto, *Neuroscience Letters* **186**, 127-130 1995.
4. C.E. Chapman, G. Spidalieri, and Y. Lamarre, *Brain Research* **309**, 63-77, 1984.
5. S. Ferraina and L. Bianchi, *Experimental Brain Research* **99**, 175-178, 1994.
6. J. Seal, C. Gross, D. Doudet, and B. Bioulac, *Neuroscience Letters* **36**, 145-150, 1983.
7. A. Iriki, M. Tanaka, and Y. Iwamura, *Neuroreport.* **7**, 2325-2330, 1996.
8. R.A. Andersen, C. Asanuma, G. Essick, and R.M. Siegel, *J. Comp. Neurol.* **296**, 65-113, 1990.
9. N. Forss, N, Hari, R, Salmelin, A. Ahonen, M. Hämäläinen, M. Kajola, J. Knuutila, and J. Simola, *J. Exp Brain Res* **99**, 309-315, 1994.
10. M. Hoshiyama, R. Kakigi, S. Koyama, S. Watanabe, and M. Shimojo, *Brain Topog,* **10**(1), 23-30, 1997.
11. D.R. Gitelman, N.M. Alpert, S. Kosslyn, K. Daffner, L. Scinto, W. Thompson, and M.-

M. Mesalum, *Annals of Neurology* **39**, 175-179, 1996.

12. C. Kertzman, U. Schwarz, T.A. Zeffiro, and M. Hallett, *Exp. Brain Res*. **114**, 170-183, 1997.
13. M.J. Catalan, M. Honda, R.A. Weeks, L.G. Cohen, and M. Hallett, *Brain* **121**, 253-264, 1998.
14. A.M. Gordon, J.-H. Lee, D. Flament, K. Ugurbil, and T.J. Ebner, *Exp. Brain Res.* **121**, 153-166, 1998.
15. R. Kawashima, B.T. O'Sullivan, and P.E. Roland, *Proc. Natl. Acad. Sci. USA*, **92**: 5969-5972, 1995.
16. N. Hadjikhani and P.E. Roland, *J. Neurosci*, **19**, 1072-1084, 1998.